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HAWAII AGRICULTURAL EXPERIMENT STATION,
J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 38.

EFFECT OF FERTILIZERS ON THE PHYSICAL PROPERTIES OF HAWAIIAN SOILS.

BY

WILLIAM McGEORGE,
Assistant Chemist.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 1, 1914.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 38 of the Hawaii Agricultural Experiment Station, a paper dealing with the Effect of Fertilizers on the Physical Properties of Hawaiian Soils, by William McGeorge, assistant chemist of this station. The peculiar constitution of Hawaiian soils makes a study of the physical properties of these soils one of unusual importance. In this paper there are described systematic experiments made to determine the effect of various fertilizers upon capillarity, percolation, flocculation, cohesion, apparent specific gravity, vapor pressure, and hygroscopic moisture. Before it is possible to reach a thorough understanding of Hawaiian soils it has been found necessary to study them from all standpoints. The paper is a contribution to the knowledge of the physical properties of soils and particularly of the effect of fertilizers in other ways than as plant food.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

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THE EFFECT OF FERTILIZERS ON THE PHYSICAL PROPERTIES OF HAWAIIAN SOILS.

INTRODUCTION.

It has been the custom in Hawaii since agriculture was first placed upon a commercial basis to stimulate crops with heavy applications of mineral fertilizers. This procedure has been maintained in spite of the fact that a majority of the soils are naturally well supplied with plant food, in some instances abnormally so.

Hawaiian soils are of such a nature that the maintenance of the best possible physical state is imperative. They are derived from the disintegration of basaltic lava, have since been impregnated with coral limestone in many of the lowlands and with large amounts of organic matter in the uplands, where the rainfall is high and the vegetation profuse. Being derived from highly basic rocks, the resulting soils are highly basic in composition. The silica content varies from 15 to 50 per cent, while the basic constituents, iron and aluminum, compose the major part of the remainder. The tendency of these metals to form hydrates or silicates, their influence upon the mechanical structure, drainage, climatic conditions, temperature, aeration, and above all the effect upon the moisture supply, are matters which demand the careful consideration of agriculturists in these islands.

Soil moisture is a prime factor in successful plant growth. It not only influences the physical condition but also acts as a vehicle for the transmission of plant food from the soil to the plant. Since all mineral and many organic substances are more or less soluble in water and since all dissolved material is known to affect the physical properties of the solvent, it may be concluded that the properties of soil moisture and also the physical condition of the soil are partially dependent upon the composition of the soil solution.

These physical properties include capillarity, percolation, flocculation, cohesion, apparent specific gravity, vapor pressure, and hygroscopic moisture. Although the laboratory determinations of these properties of a soil and of the effect of salts thereon have little direct practical value, since the soil in such cases is not in a natural state, and other conditions are abnormal, they may be useful for

studying the relationship of different soil types and the effect of fertilizers upon the physical factors influencing plant growth.

From previous work in this laboratory and the experiences of practical farmers, physical factors appear to play a large part in the fertility of Hawaiian soils. The effects of heat and volatile antiseptics, the action of lime, the high absorptive power for fertilizers, the difficulties in drainage, high cost of tillage, and the peculiar biological effects that ensue, seem to be very largely explainable on a physical basis and to be referable in part to colloids.

In view of the above facts, this station has devoted considerable time to investigations upon the physical properties of soils and the function of fertilizers, other than as a source of plant food, with special reference to the movement of soil moisture. It is quite generally conceded that no simple explanation of the influence of fertilizers upon the soil or the plant is possible.

SOIL TYPES.

As in previous investigations upon soils in this laboratory, those of widely differing chemical and physical characteristics were chosen. The following tables show the physical composition and properties of these types. In Table I will be found the mechanical composition as determined by sedimentation according to Hall.[1]

TABLE I.—*Mechanical analyses of the soils.*

Soil No.	Moisture.	Volatile matter.	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Fine silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
428	13.80	25.65	11.89	28.26	13.63	4.64	1.53	0.60
448	12.45	28.83	1.70	7.52	14.29	11.75	17.49	5.97
516	10.41	17.64	3.40	5.29	29.66	10.30	15.75	7.55
530	3.58	13.90	0.49		5.76	10.34	37.97	27.96
542	7.98	17.81	.81		31.26	13.39	17.79	10.96
573	12.26	20.44	1.50		31.48	19.10	11.93	3.29
574	7.60	13.96	.36	1.15	8.07	9.35	24.90	34.87

Of the above soil No. 428 is a dark-colored, highly organic, sandy soil from Glenwood, Olaa, Hawaii.

Soil No. 448 is a yellow silty sand from Hilo, Hawaii.

Soil No. 516 is a sample of manganiferous soil from the Wahiawa district, Oahu. It has a chocolate-brown color, silty texture, and maintains an excellent mechanical condition.

Soils Nos. 530 and 574 are samples of red-clay soils, the former of a light and the latter of a dark red color.

Soil No. 542 is a titaniferous soil of grayish red color and silty texture. Its physical condition is very similar to that of soil No. 516.

Soil No. 573 is a "dust" soil from the island of Hawaii. It is a dark-colored, highly organic silt, and very productive.

[1] The Soil. London, 1908, 2. ed., p. 51.

WATER CAPACITY OF SOILS.

Table II contains data illustrating the water capacities of these soils. Columns 4 and 5 show the percentage of water by weight and volume, respectively, required to saturate the soil, and columns 6 and 7 show the percentage by weight and volume required to saturate and fill interstitial spaces.

TABLE II.—*Water capacity of the soils.*

Soil No.	Weight of soil.	Volume of soil.	Percentage of water to saturate.		Percentage of water to saturate and fill spaces.	
			Weight.	Volume.	Weight.	Volume.
	Gm.	*Cc.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
428	150	177	61.1	51.8	64.8	55.1
448	150	168	60.2	53.7	64.3	57.5
516	150	176	66.3	56.5	71.6	61.0
530	150	132	43.7	49.6	48.3	54.7
542	150	160	61.7	57.8	63.7	59.7
573	150	189	76.3	60.7	76.3	60.7
574	150	161	50.3	46.9	62.6	58.3

SPECIFIC GRAVITY.

In Table III are given the specific gravities, both real and apparent, as well as the comparative volume occupied by 10 grams of these soils, excluding interstitial spaces, as determined upon the air-dry soils.

TABLE III.—*Specific gravity and volume of the soils.*

Soil No.	Real specific gravity.	Apparent specific gravity.	Volume occupied.	Soil No.	Real specific gravity.	Apparent specific gravity.	Volume occupied.
			Cc.				*Cc.*
428	2.4825	0.8474	4.03	542	2.8784	0.9375	3.48
448	2.5264	.8929	3.96	573	2.4454	.7936	4.09
516	2.8351	.8522	3.53	574	2.9087	.9316	3.46
530	2.9438	1.1363	3.40				

The foregoing data, while of more or less empirical nature, indicate the variation in physical properties of Hawaiian types of soil. The clays show the highest specific gravity, both real and apparent, the clay silts and silts next, while the sandy soils show the lowest. The opposite relation exists with regard to the volume and water capacity.

CAPILLARY MOVEMENT.

Upon the capillary movement of water more than upon any other physical factor is the plant dependent for successful growth. The functions of capillary water are many and involve the transmission of plant food from the soil to the plant, sustenance of the enormous evaporation during the heat of the day, and the like. By means of

this property water tends to distribute itself in all directions throughout the soil.

There may be properly considered to be three kinds of water present in soils—capillary, gravitation, and hygroscopic moisture. The capillary water is that which will not drain away but is held around the soil particles in the form of a moisture film; that is to say, there is an equilibrium between the forces of gravity and surface tension. However, capillary action is itself dependent upon and absolutely governed by such subfactors as density or gravity, viscosity, surface tension of the soil solution, and the size and composition (both organic and inorganic) of the soil particles.

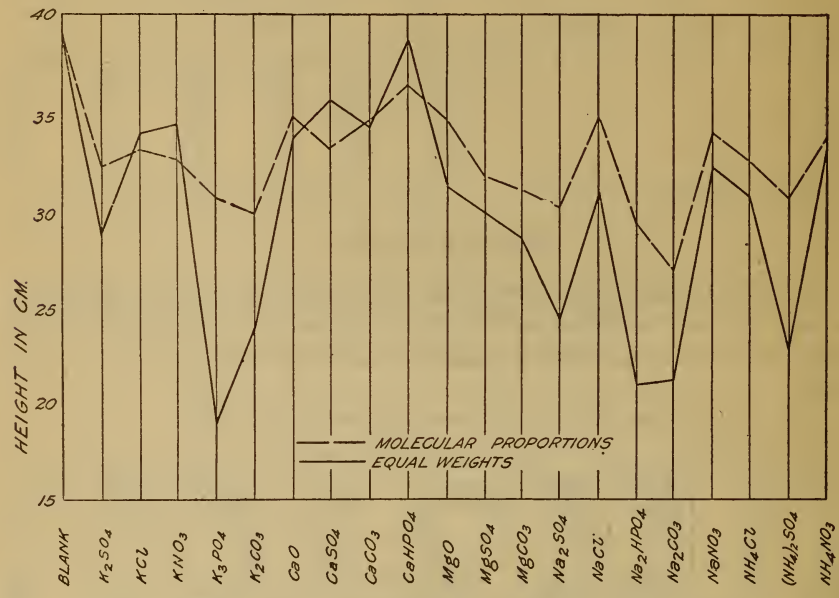

FIG. 1.—Relative capillarity following addition of salts in equal quantity and in molecular proportions.

When an object is removed from an immersion in water it retains a thin film upon its surface through the property of surface tension. In the same manner the soil particles are surrounded by a film or elastic membrane of water under a high pressure, the thickness varying within certain limits with the moisture content of the soil. As water is lost at the surface by evaporation or around the roots by absorption, there is a movement of water in the direction of increased tension, thereby tending to maintain an equal distribution of water. On the other hand, viscosity, acting in an opposite manner from surface tension, tends to retard the movement of water.

Water in soils is never pure, and all dissolved substances affect the degree of surface tension and viscosity of the solvent. Practically

all inorganic salts increase the surface tension of water while organic substances decrease it. On the other hand, the opposite relation exists with regard to viscosity. A series of experiments made at the Maryland Experiment Station [1] upon the surface tension of soil extracts show it to be considerably less than pure water. These and many other facts indicate the complexity of the application of theoretic principles to soils.

The capillary power of a soil is generally measured by the height to which water will rise in a soil column, although it may take place in all directions in soils and varies greatly according to the mechanical composition. The present study of capillarity was carried out in 1-inch glass tubes. Experiments were made not only with soils but also with silica sand and kaolin to ascertain the relation of these materials to soils. In all about 40 salts, fertilizer materials, and mixtures were used, including several organic manures. As a means of studying the effect of these salts, comparisons were made both when added in amounts proportional to their molecular weights and when added in equal amounts. Also measurements were made upon the variation in height to which the water would rise as affected by amounts of the salt varying from 0.06 to 6.66 per cent. In all cases the salts were added in small amounts.

Before presenting the data obtained in these experiments it is of interest to know the relative capillary activity of the soils in question. This is shown in Table IV, in which the figures were obtained by allowing the soil column to stand in about one-half inch of water for 78 days.

TABLE IV.—*Capillary rise of water in the soils.*

Soil No.	6 hours.	24 hours.	48 hours.	4 days.	5 days.	6 days.	7 days.	9 days.	11 days.	19 days.	32 days.	43 days.	78 days.
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
448	26.8	35.5	40.9	46.0	47.8	49.1	50.3	52.1	54.0	60.4	67.0	70.8	82.5
530	22.4	29.1	34.4	40.0	41.6	42.5	43.8	45.2	46.7	51.0	55.3	.....	71.5
428	31.6	38.1	42.9	47.3	49.0	50.4	51.5	53.8	55.6	58.4	62.1	64.8	76.5
542	39.8	51.3	57.3	62.7	64.6	65.9	67.8	70.6	72.8	79.3	86.6	89.8	100.0
516	36.8	47.8	55.2	62.0	64.0	65.0	66.8	69.2	71.2	76.4	84.8	88.7	100.0
573	41.0	56.6	64.2	69.9	79.0	81.6	83.5	88.4	91.6	100.8	109.8	[1] 115.6	.....
574	33.7	40.1	44.0	45.1	45.1	45.1	45.1	45.1	.....	.....	50.5	.....	63.0

[1] Top of column.

The highly organic silty soil showed the greatest capillary rise, the clay soils least, while the sandy soils were intermediate.

In filling the tubes it is necessary to exercise considerable care in order to obtain a uniform mixture. This is made possible by projecting a long wire with a loop on the end into the tube and withdrawing it with a rotary motion.

[1] U. S. Dept. Agr., Weather Bur. Bul. 4 (1892), p. 16.

EFFECT OF VARIOUS SALTS IN MOLECULAR PROPORTIONS.

In studying the relations of the properties of salts of widely varying molecular composition it is imperative that a definite procedure be established. With this idea in mind the following curve (fig. 1, p. 10) is presented to show the difference in results obtained when the salts were added in equal amounts and in molecular proportions to soil No. 530. The former rate was 0.5 gram of basic oxid per 100 grams of soil and the latter as follows: Calcium carbonate, with a molecular weight of approximately 100, was chosen as a standard and added at the rate of 0.1 per cent, the other salts in greater or less amounts in proportion to their molecular weights.

From these curves it appears that as a whole the general property of a given salt is to affect the soil similarly whether added in equal weights or in molecular proportions. This is at least true of the capillary activity. The curves throughout are very similar and indicate that an increase in the concentration of the salt results in a diminished capillary activity.

This variation in activity as affected by increasing the concentration of the salt suggested a further study of the phenomenon, the results of which are given in Table V. Three types of soil and silica sand were used and the amount of salt used varied from none to 10 grams per 150 grams of soil.

TABLE V.—*Capillary rise as affected by increase in percentage of salt added.*

Salts.	Percentage of salt added.													
	Soil No. 530.							Soil No. 448.						
	0.00	0.06	0.16	0.33	0.66	3.33	6.66	0.00	0.06	0.16	0.33	0.66	3.33	6.66
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
CaO	37.3	34.1	33.2	32.2	33.5	18.7	12.5	30	35.0	36.5	36.0	37.0	34.0	29.0
$NaNO_3$	37.3	34.0	33.0	31.4	31.5	28.0	26.2	30	35.9	37.5	36.0	36.0	34.2	33.0
$(NH_4)_2SO_4$	37.3	31.9	31.8	28.6	25.5	21.1	21.4	30	37.6	35.3	36.0	34.2	31.0	29.8
$CaSO_4$	34.0	29.8	29.3	29.6	28.5	29 8	33.4	30	34.2	34.0	34.4	33.2	34.9	36.0
$CaH(PO_4)$	37.3	35.5	37.8	37.2	38.8	32.7	23.3	30	34.6	35.4	34.9	37.0	38.3	38.8
$CaCO_3$	37.3	35.4	33.0	31.8	33.8	35.3	38.0	30	33.3	32.7	32.2	34.1	35.9	38.5
K_3PO_4	34.0	31.0	29.0	25.9	26.0	21.7	13.9	30	34.9	33.6	33.0	31.4	31.1	24.0
KCl	34.0	28.7	27.8	29.0	28.0	26.5	26.0	30	34.2	35.0	34.4	35.0	36.3	34.6
$MgSO_4$	37.3	32.5	30.6	27.9	27.2	21.9	21.7	30	33.1	38.0	34.8	35.8	31.0	27.6
NH_4Cl	37.3	31.8	30.1	30.5	29.2	26.4	28.2	30	34.2	34.2	33.2	35.8	34.5	32.3
Na_2CO_3	37.3	28.4	24.3	21.4	18.7	9.4	6.9	30	32.6	33.1	30.1	29.5	17.4	14.8
K_2SO_4	37.3	32.3	31.8	30.0	28.2	26.0	25.8	30	36.4	36.9	36.4	34.8	31.5	31.5

Salts.	Soil No. 428.							Silica sand.						
CaO	29.0	37.0	36.1	38.0	40.0	33.2	26.2	9 8	7.3	6.4	6.9	7.0	20.0	28.8
$NaNO_3$	29.0	38.0	38.0	37.4	38.0	35.5	34.8	9.8	10.9	12.4	13.7	13.7	12.1	11.4
$(NH_4)_2SO_4$	29.0	37.9	34.9	34.6	35.0	33.5	29.4	9.8	12.2	12.6	12.6	12.6	12.3	12.0
$CaSO_4$	29.0	37.0	38.0	35.3	38.4	38.8	41.2	10.2	12.1	16.7	13.0	14.5	22.2	34.2
$CaH(PO_4)$	29.0	38.6	36.5	39.0	40.0	38.2	34.1	10.2	13.9	16.8	15.3	14.4	14.5	18.4
$CaCO_3$	29.0	37.7	38.0	35.2	36.3	38.9	37.6	10.2	16.6	14.9	18.3	20.5	27.4	32.6
K_3PO_4	29.0	38.8	37.9	37.0	36.5	33.1	24.2	10.2	12.4	14.6	16.6	15.7	11.6	12.2
KCl	28.6	36.8	36.8	36.6	36.9	37.1	35.2	9.8	10.9	13.5	11.9	12.4	14.1	16.1
$MgSO_4$	30.7	43.2	42.9	42.1	42.8	40.0	36.1	9.8	13.9	16.5	13.8	13.7	13.7	13.7
NH_4Cl	30.7	41.4	41.5	41.2	40.8	37.0	34.9	9.8	11.2	13.3	12.3	11.9	10.9	11.4
Na_2CO_3	30.7	36.8	37.7	36.1	39.0	34.4	25.4	9.8	15.9	16.4	14.7	15.7	17.5	17.5
K_2SO_4	29.0	37.2	35.7	34.7	35.2	35.2	35.0	9.8	13.7	14.1	14.5	13.9	13.0	16.2

Effect on soil No. 530.—The table shows that all the salts, with the possible exception of calcium phosphate, cause a regular decrease in rise of moisture with increase in concentration. Calcium phosphate, when added at the rate of 0.66 per cent, increases the activity.

Effect on soil No. 448.—Here again the effects of various salts seem to be related with few exceptions and the tendency is toward an increase in capillarity up to a certain concentration beyond which a further addition of the salt materially retards the rise of water. Exceptions to this rule are sulphate and carbonate of calcium, which, being difficultly soluble, would materially change the physical nature of the soil, and calcium phosphate, which, being a soluble salt, exerts a chemical effect.

Effect on soil No. 428.—The effects of salts upon the capillary activity in this soil are similar to those in the former except that the variation in moisture rise is greater. The soil, containing a greater percentage of sand, shows a higher rise in moisture.

Effect on silica sand.—Conditions in sand are ideal for measuring the effect of salts upon capillary action within certain limits, beyond which any further concentration gives misleading results. This is due to the filling of the pore spaces and the subsequent drawing up of moisture, caused by the salts as they become dissolved by the rising moisture, rather than to the action of the salt upon the activity of the film surrounding the grains. Taken as a whole the results with a concentration of salt below 3.3 per cent are very similar to those obtained with the sandy soil, the more marked variation being in the action of lime.

Apparently the most important inference to be drawn from the foregoing table is that the action of a high concentration of a salt in most instances only magnifies that of a small application.

With this fact determined it was decided that the salts should be used in as small amounts as possible and in amounts proportional to their molecular weights, thus more nearly approaching normal condition. The same molecular proportions as previously mentioned were used, while the fertilizing substances, such as mineral phosphates, blood, etc., were added at the rate of 0.1 per cent. The results given in Table VI show the relation of various salts to the rise of moisture in several of the dominating types of Hawaiian soils.

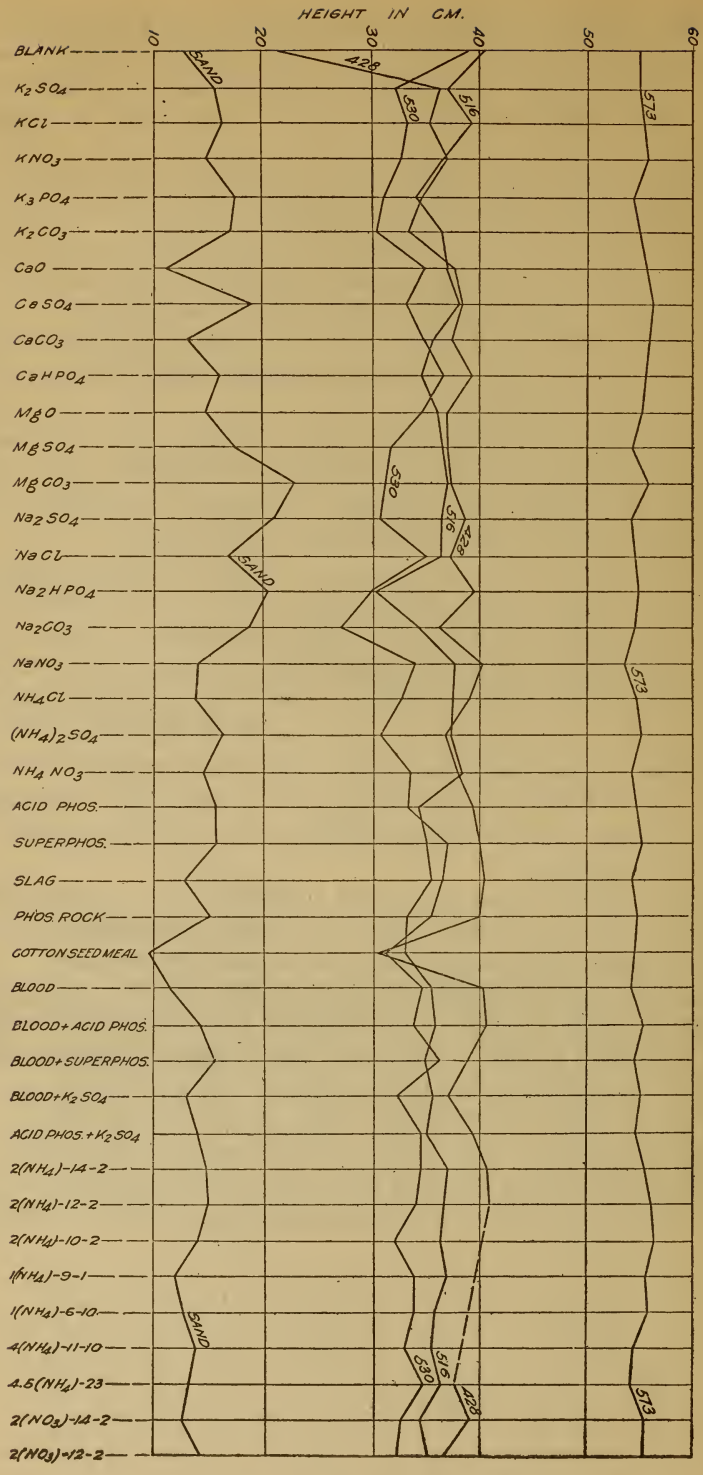

FIG. 2.—Effect of salts and fertilizers on capillary rise of moisture.

TABLE VI.—*Effect of various salts and fertilizers on capillarity, the salts being added in molecular proportions.*

Salts and fertilizers.	Weight per 200 gm. soil.	Soil No. 488.	Soil No. 530.	Soil No. 573.	Soil No. 516.	Soil No. 542.	Soil No. 428.	Kaolin.	Sand.
	Gm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
K_2SO_4	0.35	45.9	32.7	55.0	37.1	39.0	36.4	23.6	15.4
KCl	.15	46.6	33.4	55.3	39.0	39.1	35.1	25.4	16.2
KNO_3	.20	48.8	33.0	55.7	36.6	39.8	36.8	24.8	14.6
K_3PO_4	.42	42.1	31.1	54.2	34.1	36.7	34.7	23.3	17.5
K_2CO_3	.28	44.8	30.2	54.9	36.5	38.3	33.5	23.6	17.0
CaO	.11	46.6	35.0	55.5	36.9	40.7	37.8	26.1	10.8
$CaSO_4$	.27	46.3	33.4	56.2	38.3	41.4	38.3	21.9	18.9
$CaCO_3$	.20	47.6	34.8	56.0	35.8	42.9	37.6	25.2	12.8
$CaHPO_4$	.46	45.2	36.9	55.5	34.5	40.4	39.2	25.6	15.9
MgO	.08	47.5	34.9	55.1	36.2	40.3	37.0	24.7	14.5
$MgSO_4$	.24	47.2	31.9	54.2	36.5	40.4	37.0	25.0	17.5
$MgCO_3$	.70	44.3	31.3	55.8	37.1	41.7	37.0	26.5	23.0
Na_2SO_4	.28	45.4	30.5	54.0	36.4	38.7	38.6	22.1	21.1
NaCl	.12	46.5	35.2	54.5	36.4	41.3	37.1	23.6	16.7
Na_2HPO_4	.72	45.9	29.7	54.7	30.0	36.9	39.6	20.2	20.3
Na_2CO_3	.21	45.0	27.2	54.4	34.7	40.0	36.2	21.2	18.7
$NaNO_3$	.17	45.5	34.2	53.7	38.0	40.4	40.3	22.8	14.0
NH_4Cl	.11	48.9	32.8	54.7	37.8	41.7	39.1	25.7	13.9
$(NH_4)_2SO_4$	.26	40.0	31.0	55.2	37.6	42.1	37.0	24.1	16.5
$(NH_4)NO_3$	.16	47.8	34.0	54.1	38.5	42.6	38.1	25.9	14.4
Acid phosphate	.20	45.4	33.9	54.9	34.5	40.2	39.5	26.0	15.8
Superphosphate	.20	46.5	37.4	55.2	35.2	40.5	40.0	25.7	15.8
Slag	.20	46.8	37.0	54.4	35.4	42.3	40.4	26.3	11.8
Phosphate rock	.20	45.7	35.7	54.9	33.6	42.0	39.9	.....	15.0
Cottonseed meal	.20	44.6	31.4	54.8	33.4	37.7	31.4	26.6	9.5
Blood	.20	47.6	34.8	54.2	35.7	41.7	40.3	27.4	11.7
Blood and acid phosphate	.20	47.1	34.0	55.5	36.2	42.5	40.7	21.6	14.2
Blood and superphosphate	.20	47.4	36.8	54.5	34.9	42.9	39.0	26.4	15.8
Blood and K_2SO_4	.20	47.9	32.8	55.4	36.0	41.8	37.4	26.7	12.1
Acid phosphate and K_2SO_4	.20	47.9	35.4	54.6	35.1	40.7	39.8	26.5	14.2
2(NH4)-14-21	.20	47.1	35.0	55.9	37.5	42.4	41.1	24.6	14.8
2(NH4)-12-21	.20	47.7	34.5	56.6	37.3	42.3	41.5	24.7	15.3
2(NH4)-10-21	.20	46.8	32.8	56.9	37.1	40.7	.....	26.8	14.1
1(NH4)-9-11	.20	47.5	34.3	55.8	37.5	42.0	.....	25.5	12.2
1(NH4)-6-101	.20	47.6	34.3	55.9	36.1	41.2	.....	24.6	12.9
4(NH4)-11-101	.20	46.3	33.5	54.6	35.9	40.9	.....	26.6	13.9
4.5(NH4)-23-01	.20	47.7	35.5	54.6	37.0	40.9	38.3	23.9	13.3
2(NO_3)-14-22	.20	47.6	33.3	56.0	35.0	41.9	39.6	26.4	12.8
2(NO_3)-12-22	.20	46.8	33.0	55.9	35.8	40.8	37.5	24.5	14.2
Check	.....	35.5	39.2	55.0	40.4	44.9	28.0	28.0	12.9
Time in hours	.....	24	69	24	8	8	21	26	24

[1] Fertilizer mixtures supplying nitrogen (in ammonium sulphate), phosphoric acid, and potash in the order and proportions (percentages) given.
[2] Fertilizer mixtures similar to those referred to in footnote 1 except that nitrogen was supplied in sodium nitrate.

The accompanying curve (fig. 2) illustrates the effect of the fertilizers on capillarity more clearly than the table.

Effect on silica sand.—Here it is possible to explain most of the results by applying the known effects of salts upon the capillary activity of their solvents. Inorganic salts increase, and organic substances retard, the rise of water. The principal exceptions to this rule are calcium oxid and slag.

Effect on soils Nos. 428 and 448.—With these soils the rate of rise in moisture is quite rapid at first, decreasing to a very slow rise in a short time. All organic and inorganic substances added produced an increase in rate of capillarity within the time limits of the experiment. These soils have a coarse texture, contain a high percentage of organic matter and of hygroscopic and combined water, and hence indicate the relation of these properties to the capillary activity of soil extracts.

Effect on soil No. 573.—This soil, of all the types examined, possessed the greatest capillary activity and was least affected by the addition of salts. In fact, it may be assumed that the capillary activity of this soil is unaffected by the addition of outside agents as the results agree with the check within the limits of experimental error. In view of the above facts, a series of experiments was carried out in which the amount of salt added was doubled, the results of which agreed very closely with those reported above.

Effect on soils Nos. 516 and 542.—These soils are of very similar mechanical composition but belong to different chemical types. The data presented indicate that the clay tends to dominate the capillary activity of this type of soil in that the addition of all substances diminished capillarity.

Effect on soil No. 530.—The physical character of this type of soil is such that chemical agents would be expected to materially affect its texture. This theory is borne out in the diminished capillary activity noted in every instance.

Effect on kaolin.—The diminished capillarity observed in the study of the effect of salts on kaolin shows a direct relationship between this substance and clay soils.

Any attempt at classification of the above results according to theoretic considerations only indicates the complexity of applying any one theory to soils. More than one factor evidently enters into play to which it is necessary to give due consideration. That fertilizers do markedly affect capillarity is clearly shown. In using mixed fertilizers there is little variation in rise as related to variation in mixture. Those in which nitrates are used show decrease in water rise as compared with those containing ammonium sulphate.

EFFECT OF BASICITY ON CAPILLARITY.

Organic manures, as compared with the salts, retard the rise in the sandy soils and decrease the rise in others. As a rule, magnesium salts affect capillarity less than the calcium salts, potassium salts less than ammonium, sodium less than potassium, and the monobasic salts in most instances less than the dibasic. Among the monobasic salts, carbonates and phosphates show the lowest, sulphates next, nitrates next, and chlorids the highest water line.

With the phosphates the rise of moisture seems to depend upon the acidity or basicity of the salt. This may be observed by comparing data in Table VII with those in Table VI under the phosphates of lime. Here also the relation between acidity and rise of moisture is similar to that observed in the case of the potash salt.

TABLE VII.—*Showing effect of basicity on capillarity.*

	Weight added.	Height.		Weight added.	Height.
	Gm.	*Cm.*		*Gm.*	*Cm.*
KH_2PO_4	[1] 1.42	32.6	KH_2PO_4	0.5	32.6
K_2HPO_4	1.92	30.3	K_2HPO_4	.5	30.9
K_3PO_4	1.75	23.3	K_3PO_4	.5	29.0

[1] Equivalent to 0.5 per cent K_2O.

The easily hydrolyzable salts, phosphates and carbonates of the alkalis, show the lowest water table. However, they are much more active in organic soils due to their solvent action or chemical reaction with the organic matter present. These hydrolyzable salts also cause a swelling of the clay particles which, in Hawaiian soils, are partly composed of iron and aluminum hydrates and are conducive to the colloidal state, thus closing the pores, increasing friction, and lowering the rates of moisture rise.

PERCOLATION.

All moisture which passes below the surface, in excess of that held through capillary action or surface tension, is subject to the laws of gravity. The rate of movement, however, is dependent upon various factors, such as the size and composition of the soil particles, height of soil surface above water table, surface tension, and viscosity of the soil solution.

Percolation is quite generally held to be most rapid in soils in which capillary activity is greatest, decreasing with height of column, and is faster in wet soils than in dry soils. Clay, of course, offers the greatest physical resistance to the passage of water and the resistance varies with the degree of aggregation of the clay particles.

The rate with which water will pass downward, then, depends upon the physical state of the soil and this in turn varies with the arrangement of the soil particles. Both of these properties, however, are affected by the nature of the soil solution, percolation decreasing with increase in concentration.

For studying the effect of fertilizers upon this property of soils 1-inch glass tubes containing soil columns of about 30 centimeters were fitted up as in studying the capillary activity. These tubes were connected with a constant supply reservoir which maintained a 1-inch head of water in the tubes, and the water passing through the soil was measured at intervals. The totals of these measurements are given in Table VIII.

TABLE VIII.—*Percolation as affected by salts and fertilizers.*

Salts and fertilizers.	Soil No. 530. Time of experiment. 6 days.	Soil No. 573. 7 days.	Soil No. 428. 2¾ days.	Soil No. 516. 4 days.	Salts and fertilizers.	Soil No. 530. 6 days.	Soil No. 573. 7 days.	Soil No. 428. 2¾ days.	Soil No. 516. 4 days.
	Cc.	*Cc.*	*Cc.*	*Cc.*		*Cc.*	*Cc.*	*Cc.*	*Cc.*
Potassium sulphate	1,757	1,316	9,212	2,312	Magnesium sulphate	1,838	1,413	2,349	3,404
Potassium chlorid	3,543	1,265	5,300	4,123	Blank	8,687	1,628	[1]	7,086
Potassium phosphate	2,602	1,546	4,044	3,077	Sodium phosphate	1,765	1,253	3,545	3,293
Calcium oxid	3,824	1,555	2,985	4,851	Sodium carbonate	2,021	1,787	3,601	2,633
Calcium sulphate	940	1,939	2,134	5,635	Sodium nitrate	4,481	1,189	3,445	1,649
Calcium carbonate	661	1,564	2,516	4,569	Ammonium chlorid	4,162	1,452	5,038	3,355
Calcium phosphate	1,902	1,484	2,795	5,489	Ammonium sulphate	488	1,530	6,612	2,987
Magnesium oxid	2,008	1,504	2,166	5,093					

	7 days.	7 days.	40 hours.	3 days.		7 days.	7 days.	40 hours.	3 days.
	Cc.	*Cc.*	*Cc.*	*Cc.*		*Cc.*	*Cc.*	*Cc.*	*Cc.*
Superphosphate	1,688	1,940	2,568	1,581	Potassium sulphate and acid phosphate	3,491	1,321	2,693	4,631
Slag	4,784	1,588	3,256	3,632	2(NH4)-14-2 [3]	2,305	1,618	1,945	4,060
Phosphate rock	1,990	1,675	2,546	3,902	1(NH4)-9-1 [3]	3,685	1,636	3,852	2,847
Cottonseed meal	2,432	1,443	1,924	4,659	4(NH4)-11-10 [3]	2,763	1,331	1,365	3,239
Blood	1,892	1,456	4,027	3,656	4.5(NH4)-23-0 [3]	3,198	1,381	2,076	4,826
Blood and acid phosphate	1,476	1,567	2,012	3,324	2(NO3)-14-2 [4]	3,745	1,480	2,044	5,006
Blank	5,865	1,710	11,936	[2] 7,226	Acid phosphate	3,209	1,649	1,308	2,456
Blood and potassium sulphate	4,753	1,423	3,526	1,715					

[1] Stopped after 2¾ days.
[2] Stopped after 2 days.
[3] Fertilizer mixtures supplying nitrogen (in ammonium sulphate), phosphoric acid, and potash in the order and proportions (percentages) given.
[4] Fertilizer mixture similar to those referred to in footnote 3 except that nitrogen was supplied in sodium nitrate.

A glance at this table clearly indicates the complexity of the study of the passage of water through soils. It is quite generally conceded that those soils in which capillary activity is greatest offer the least resistance to the passage of water. Soil No. 573 fails to lend support to this theory, as does also No. 516. In these soils the capillary activity is greatest, while they offer much greater resistance to the passage of water than the sandy soils. Even the heavy clay soil offers less resistance than No. 573.

As a whole the calcium salts cause less resistance than magnesium salts, ammonium less than potassium, chlorids less than sulphates in clay soils, but the sulphates least in organic soils. Mixtures in which sodium nitrate is used cause less resistance to flow of water than where ammonium salts were used.

Soil No. 530.—All the salts and fertilizers added to this type retarded the percolation of water. There is a slight relation between the degree of resistance and the flocculating power of the salts. As a rule the most deflocculated samples were among those that offered the greatest resistance and vice versa, as was found by examining

the soils at the completion of the experiments. The organic manures resist the flow also but when mixed with mineral fertilizers the resistance is less. The data taken from daily observations, not indicated in the table, show that the passage of water in practically all the tubes decreased steadily from day to day after the salts became diffused throughout the soil and the clay began to swell. This applies only to soils Nos. 530 and 573.

Soil No. 573.—Percolation through this soil was very slow and regular. Like capillary activity, salts had very little effect upon it. The amount of water passing through the tubes was less on the last day of the experiment than on the first day. There is practically no clay present in this soil, so that the action of the salts is probably upon the organic matter. This soil is the only one in which any salt increased the rate of flow. These salts were calcium sulphate, sodium carbonate, and superphosphate. Sodium nitrate strongly retarded percolation.

Soil No. 428.—In this instance it was not possible with the equipment available to maintain a constant head of water, due to the large volume which would percolate during the night. All the materials used at first decreased the rate of percolation but the daily rate increased steadily, for which reason the series was not carried out so completely as in the two previous soils. This increase was probably due to a washing out of the substances added. The action of sodium carbonate and sodium nitrate was very similar and unlike the effects in the above organic soil. The organic manures resist percolation quite strongly. The calcium and magnesium salts offer the greatest resistance, sodium salts next, ammonium salts next, and potash salts the least.

Soil No. 516.—This soil, owing to its mechanical condition and low organic content, offers little resistance to percolation of water. The effect of adding any agent is to decrease the flow. However, the results obtained indicate that some soils are capable of restoring their equilibrium, as is shown by the fact that the depression of the first day became less as diffusion became more complete. The dibasic salts offer less resistance to percolation than the monobasic.

FLOCCULATION.

The rôle of flocculation in soils is one of considerable importance in a study of soils such as occur in these islands. The red clay is a type possessing an unusual tenacity and requires judicious handling to prevent puddling and to maintain the colloidal clay in the best physical condition. Various investigators, recognizing that a soluble salt will bring about the flocculation of the suspended material in a turbid liquid, have studied the relation of this to the improve-

ment of the texture in heavy soils. Indeed this is said to be the primary function of lime, which is one of the most universally applied soil amendments.

The above studies indicate that the maintenance of a crumb structure is seriously menaced by the presence of even a trace of certain compounds. Hence flocculating or deflocculating agents alter the soil structure. The latter not only destroy the compound aggregates but also bring about a diffusion or swelling of the colloidal clay. This results in a closing of the pore spaces, shutting out the air, development of acid conditions, and menacing the whole cycle of normal soil transformations.

Since it is conceded that the best physical state, known as a crumb structure, is due to flocculation of the smaller grains into aggregates, the conclusion is obvious that the study of conditions conducive to the formation of a colloidal state and the relation of salts to this state may be of considerable local application.

As a means of studying this property of Hawaiian clay a sample of highly puddled soil was chosen, one in which the clay would remain in suspension for weeks. A stock suspension of this soil sufficient for all experiments was prepared, so that a suspension of known concentration would be available. The degree of flocculation, to a certain extent, depends upon the relation of the amount of clay in suspension to the strength of the flocculating agent.

Normal solutions were prepared of all the salts used in previous experiments, except the slightly soluble ones, in which case saturated solutions were made. By a series of preliminary experiments those salts having a negative or deflocculating effect were eliminated. These include potassium and sodium phosphates and carbonates. Secondly, salts causing a flocculation of the clay but not sufficiently soluble to form a normal solution were eliminated. These include the oxid, carbonate and sulphate of calcium and the oxid and carbonate of magnesium.

The comparisons were made in glass cylinders of 400 cubic centimeters capacity in which were placed 2 cubic centimeters of normal salt solution, 10 cubic centimeters of clay suspension, and 188 cubic centimeters of water, making a total of 200 cubic centimeters. This mixture was shaken and allowed to settle. In the case of the stronger flocculants this proved too great a concentration, hence the experiments were repeated with a much weaker solution. The results are given in Table IX.

TABLE IX.—*Showing relative rate of flocculation by acids and their salts.*

Salt or acid.	Time required for flocculation.		Salt or acid.	Time required for flocculation.	
	$\frac{1}{100}$-normal solution.	$\frac{1}{800}$-normal solution.		$\frac{1}{100}$-normal solution.	$\frac{1}{800}$-normal solution.
	Hours.	*Hours.*		*Hours.*	*Hours.*
H_2SO_4	1	6	NaCl	120	.....
$Al_2(SO_4)_3$	1	1	NH_4Cl	103	.....
$CaSO_4$	9	.....	HNO_3	1	2
$MgSO_4$	4	100	$Ca(NO_3)_2$	1	72
K_2SO_4	105	.....	$Mg(NO_3)_2$	2½	144
Na_2SO_4	120	.....	KNO_3	48	.....
$(NH_4)_2SO_4$	147	.....	$NaNO_3$	150	.....
HCl	1	3	NH_4NO_3	72	.....
$CaCl_2$	1	29	H_3PO_4	1½	192
$MgCl_2$	3	76	$CaHPO_4$	1½	240
KCl	165	.....	CH_3COOH	15	.....

These results agree to a certain extent with the findings of other investigators. They indicate a relationship between the valency of the salt and its flocculating power. The most active salt is aluminum sulphate, a trivalent salt and one which is highly hydrolyzed. The divalent calcium and magnesium salts of nitric, hydrochloric, and sulphuric acids are next, while the monovalent salts of sodium, potassium, and ammonium are least active. The acids are stronger than any of their divalent salts but the trivalent salt, aluminum sulphate, is stronger than any of the acids. Nitric acid is the strongest, hydrochloric second, and sulphuric third. Likewise the nitrates and chlorids are stronger than the sulphates. This indicates that the degree of flocculation is related both to the acidity and the basicity. Phosphoric and acetic acids cause much less flocculation than the other acids.

Thus far no investigator has been able to satisfactorily explain this phenomenon, although various theories have been advanced. The explanation is probably to be found within the realm of colloid chemistry. Hall and Morrison suggest that some physicist must first arrive at a satisfactory explanation of Brownian motion. They[1] have recently suggested the possible presence of free alkali derived from the partial hydrolysis of the suspended material and that flocculation ensues when these are neutralized. Hilgard assumed a chemical hydration of the fine particles of clay when in suspension which when lime was added became dehydrated, causing a flocculation of the soil particles.

Regarding the composition of soil colloids little is known. While many authors have assumed them to be inorganic it is probable that being characteristic of the states of matter from which they are formed and not of any particular substance, they may be partly organic. Free[2] suggests that organic colloids may coat the soil particles with thin films.

[1] Jour. Agr. Sci., 2 (1907), No. 3, pp. 244–256.

[2] Jour. Franklin Inst., 169 (1910), No. 6, pp. 421–438; 170 (1910), No. 1, pp. 46–57.

There is practically no doubt that colloids exist in Hawaiian soils. The physical properties indicate such to be the case. A chemical analysis of the clay shows it to be primarily a silicate of iron and aluminum with a probability of the hydrates being present also. Noncoagulable clay, by analysis, shows a higher percentage of iron and silica and less alumina than the coagulable clay. This indicates that part of the iron exists in the form of ferric hydrate.

While the chemical composition may affect the nature of the colloids and the degree of flocculation the phenomenon itself is physical. The relation is between the composition and nature of the colloidal film surrounding the clay particle and its degree of surface tension. The effects of any added acid or salt is to alter the nature of the film probably through penetration or chemical action, thereby increasing or decreasing the surface tension, depending on the nature of the added substance, and increasing or decreasing the degree of flocculation. Some authors maintain that the salt or acid actually replaces bases within the colloid, thereby altering its composition, while others maintain that it only alters the film and by washing upon a filter with water the clay will revert to its original colloidal state. This latter contention seems to apply best to the conditions found to exist in Hawaiian soils. At all events the flocculation of Hawaiian clay is influenced as follows:

(1) Most acids and neutral salts, especially electrolytes, increase the degree of flocculation.

(2) Highly dissociated acids are the strongest coagulants, and the less dissociated acids act more or less in proportion to their degree of ionization.

(3) Electrolytes of greater valency possess a greater degree of flocculation than those of lesser valency.

(4) Most highly dissociated alkalis are strongest deflocculants, as are also the alkali salts of weak acids, such as phosphoric.

(5) Ammonium hydroxid is an exception, being only slightly ionized, but at the same time it is the strongest deflocculant.

(6) The degree of flocculation depends upon the strength or valency of the anion as well as of that of the cation.

COHESION.

The film of moisture around soil particles imparts to them cohesion by which the particles are bound together. As the moisture content decreases surface tension of the film increases and the particles are drawn together. Hence, in a clay soil where shrinkage is greatest, there results the formation of cracks. There is a definite moisture content at which tenacity of the soil particles is at a minimum, the texture is best for culture, and the whole environment is most conducive to the best plant growth. The factors bringing about such

conditions depend upon the mechanical composition, the organic matter present, and the presence or absence of certain soluble substances.

As a means of measuring the effect of salts upon this cohesive property of Hawaiian soils, the procedure described by the Bureau of Soils was used.[1] In this procedure a mechanical shaker having a screening apparatus and operated by a motor is used to insure a uniform packing of the soil. By means of this apparatus a cup was filled with the soil and by means of a penetrating apparatus the weight necessary to cause a steel cone-shaped needle to penetrate a fixed depth was determined. While the results so obtained are not directly comparable with results obtained by other investigators, due to slight differences which may result from the construction of the apparatus, they are comparable among themselves.

In Table X are shown the salts used in the experiments and the penetration with varying moisture contents, 1,500 grams of soil being used in making the determinations. After each penetration water was added, as shown in the table, well mixed with the soil and allowed to stand one hour before repeating the penetration test. Five penetrations were made on each cup of soil and the average taken. The cup was refilled for further penetrations, repeating these some three or more times at each moisture content if there was any undue variation. Water was added up to the point at which it was impossible to work the soil. Salts were added at the rate of 15 grams per 1,500 grams soil, or 1 per cent of salt. Portions were taken from each cup for moisture determination.

TABLE X.—*Effect of salts on cohesion in soils under various percentages of moisture.*

SOIL NO. 573.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.
Per ct.	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*
13.43	25.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16.67	27.25	15.61	26.25	15.85	26.35	15.55	29.20	15.43	28.60	14.55	28.55	16.94	27.30
20.65	28.85	19.14	26.25	17.62	27.55	17.60	30.15	17.87	27.50	18.05	29.95	19.26	27.35
23.14	26.90	21.94	25.15	20.40	28.8	21.22	29.15	20.54	27.7	21.10	27.40	21.70	27.15
25.11	25.00	24.72	25.20	22.96	28.25	23.02	26.35	23.15	27.05	23.78	25.25	24.07	27.30

SOIL NO. 530.

3.66	50	3.90	50.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6.78	48.75	7.14	46.9	8.35	51.5	7.47	48.2	7.47	50.6	8.56	52.75	7.47	49.2
9.98	46.25	11.43	49.3	11.61	48.6	10.50	51.75	11.69	51.5	12.56	51.5	11.02	58.75
12.66	49.30	14.84	55.2	14.50	49.7	14.44	53.5	15.02	53.45	14.87	49.9	13.88	61.0
16.40	51.50	16.86	52.0	17.10	52.2	17.42	52.45	17.33	49.7	18.00	50.4	16.76	69.0
19.30	48.5	21.68	51	21.60	47.0	19.86	47.45	20.20	48.55	20.31	47.95	.....	.....

[1] U. S. Dept. Agr., Bur. Soils Bul. 50 (1908).

TABLE X.—*Effect of salts on cohesion in soils under various percentages of moisture*—Continued.

SOIL NO. 516.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.
Per ct.	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*
10.95	38.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15.14	36.65	14.19	35.95	12.33	39.4	13.09	35.90	11.49	35.3	10.19	37.15	12.18	35.6
18.54	36.3	17.77	37.15	15.96	38.3	16.51	35.9	15.01	39.8	13.98	39.30	15.62	36.9
21.26	38.45	21.16	35.0	19.12	36.35	19.11	36.2	18.22	37.45	17.46	36.5	18.79	35.65
24.13	37.5	23.67	33.3	21.71	40.05	22.46	39.55	21.86	39.5	20.90	36.95	21.25	37.45
26.71	33.9	26.11	32.55	24.77	35.60	24.95	34	22.21	37.45	22.79	36.1	23.37	37.05

SOIL NO. 428.

11.23	37.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15.11	35.40	12.97	34.6	14.44	35.1	13.14	36.6	.....	.....	.....	.....	14.18	37.05
17.96	31.6	16.42	35.95	18.39	32.95	17.30	35.25	.....	.....	.....	.....	18.08	33.95
18.50	31.75	19.10	35.0	20.00	34.5	19.50	34.4	.....	.....	.....	.....	20.76	34.7
21.90	30.3	21.98	33.1	22.75	31.25	22.42	33.05	.....	.....	.....	.....	23.25	35.25
25.33	28.4	24.96	31.15	26.62	30.5	25.34	32.75	.....	.....	.....	.....	25.87	32.1

Soil No. 573, given in Table X, is the silty organic soil. The weight required for penetration increased at first and then decreased with increase in moisture content, reaching a minimum at 25 per cent, which is apparently the optimum moisture content for this type of soil. The effect of the addition of salts is to increase the weight necessary for penetration at the optimum moisture content, that is, salts increase the cohesion of the soil particles. This is especially true of lime. The cohesion apparently does not vary with change in moisture content in the presence of sodium carbonate.

Soil No. 530.—Table X shows the relation between moisture content and cohesion for the predominating red type of clay soil. Nineteen per cent moisture represents the point above which it is impossible to work with this type, due to the fact that the soil will not pass through the screen used in the apparatus. The figures obtained show an optimum moisture content of about 10 per cent if conclusions are to be drawn from the theories advanced by previous investigators. However, 10 per cent is rather low for this type of soil and it is probable that the optimum point for plant growth is above the range of the experiment. The cohesion of this soil decreases at first, then increases up to 16 per cent moisture, followed by a second decrease. The remarkable effect of sodium carbonate (and this would apply in more or less degree to all deflocculating agents) is clearly shown in the table. Regarding the effect of other salts, little can be concluded from the data at hand. That they do affect cohesion there is no doubt, but it is impossible to definitely classify these effects.

Soil No. 516.—Here again it was not possible to determine exactly the optimum point, but 26 per cent water is probably very close to this stage. The effect of increasing the moisture content is to decrease cohesion to a certain point, followed by an increase, then descending as the optimum moisture content is approached. Potassium sulphate decreases cohesion while the rest of the salts apparently increase this property in varying degree.

Soil No. 428.—The effect of varying the moisture content of this soil differs from that observed with the other soils in that the decrease in cohesion is regular and rapid as a result of increasing the moisture content up to the optimum point. The effect of salts is to increase the cohesion of this type of soil. This fact was found to be true in every instance. Owing to a lack of sufficient soil, ammonium sulphate and sodium nitrate were not used.

Throughout this work care was exercised to subject each cup of soil to the same procedure. Penetrations were made at equal distances from the center of the cup, the weight was allowed to fall through equal heights, and similar methods used throughout. Even with these precautions it was difficult to obtain closely agreeing results from a clay soil, but very concordant results were obtained from the other types.

APPARENT SPECIFIC GRAVITY.

Closely related to cohesion and bearing directly on the swelling of soils on wetting and shrinking and cracking upon drying is the apparent specific gravity, the relation between the weight of a soil and the volume it occupies. This property has been supposed to be at a minimum at the optimum moisture content of the soil. Like all physical properties it is subject to modification and is more or less affected by the same factors that affect the cohesive power.

The same apparatus used for penetration experiments was used for the determination of the apparent specific gravity. The data were obtained by dividing the weight of the soil in the container by its volume. The results are given in Table XI.

TABLE XI.—*Effect of salts and moisture content on apparent specific gravity.*

SOIL NO. 573.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.
Per ct.		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*	
13.43	0.7017	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16.67	.6745	15.61	0.6807	15.85	0.6842	15.55	0.6868	15.43	0.6587	14.55	0.6693	16.94	0.6605
20.65	.6359	19.14	.6305	17.62	.6605	17.60	.6544	17.87	.6394	18.05	.6394	19.26	.6412
23.14	.6000	21.94	.5921	20.40	.6254	21.22	.6193	20.54	.6061	21.10	.5894	21.70	.6079
25.11	.....	24.72	.5438	22.96	.5842	23.02	.5710	23.15	.5674	23.78	.5587	24.07	.5649

TABLE XI.—*Effect of salts and moisture content on apparent specific gravity*—Contd.

SOIL NO. 530.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.
Per ct.			*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*
3.66	1.0284	3.90	1.0368	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6.78	1.0596	7.14	1.0737	8.35	1.0745	7.47	1.0622	7.47	1.0500	8.56	1.0517	7.47	1.0087
9.98	1.0886	11.43	1.0973	11.61	1.1135	10.50	1.0851	11.69	1.0956	12.52	1.1052	11.02	1.0517
12.66	1.1096	14.84	1.1289	14.50	1.1509	14.44	1.1079	15.02	1.1043	14.87	1.1079	13.88	1.0394
16.40	1.1017	16.86	1.1114	17.10	1.1070	17.42	1.0912	17.33	1.0605	18.00	1.0693	16.76	1.0079
19.30	.9640	21.68	.9745	21.60	.9096	19.86	.9447	20.20	.8789	20.31	.9184	.....	.....

SOIL NO. 516.

10.95	0.8035	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15.14	.8973	14.19	0.9026	12.33	0.8886	13.09	0.8859	11.49	0.8666	10.19	0.8684	12.18	0.8587
18.54	.9096	17.77	.9219	15.96	.9351	16.51	.9158	15.01	.9245	13.98	.9236	15.62	.9035
21.26	.8219	21.16	.8140	19.12	.8886	19.11	.8570	18.22	.8982	17.46	.9166	18.79	.8833
24.13	.7403	23.67	.7517	21.71	.8035	22.46	.7781	21.86	.8219	20.90	.8307	21.25	.8324
26.71	.6675	26.11	.6833	24.77	.7210	24.95	.7140	22.21	.7543	22.79	.7552	23.37	.7912

SOIL NO. 428.

11.23	0.7394	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15.11	.....	12.97	0.7403	14.44	0.7517	13.14	0.7245	.....	.....	.....	.....	14.18	0.8386
17.96	.7464	16.42	.7342	18.39	.7245	17.30	.7166	.....	.....	.....	.....	18.08	.7657
18.50	.7175	19.10	.7079	20.00	.7079	19.50	.7008	.....	.....	.....	.....	20.76	.7298
21.90	.6737	21.98	.6780	22.75	.6789	22.42	.6701	.....	.....	.....	.....	23.25	.6929
25.33	.6403	24.86	.6377	26.62	.6684	25.34	.6623	.....	.....	.....	.....	25.89	.6666

In soil No. 573 specific gravity decreases regularly with increase in moisture content up to the optimum both in the untreated soil and in those treated with salts. The effect of salts is not striking but in some cases increases, in others decreases, the apparent specific gravity.

In soil No. 530 the results are very similar to those obtained in the cohesion tests. This type shows an increase in specific gravity up to a maximum, above which point it decreases to what has been assumed to be the optimum point. Calcium oxid, superphosphate, ammonium sulphate, sodium nitrate, and sodium carbonate decrease the specific gravity, while potassium sulphate slightly increases it, differing considerably from their action on the previous soil.

With soil No. 516 the results are similar to those with No. 530 in that the apparent specific gravity increases with increase in moisture content to 18.5 per cent, beyond which it decreases to the optimum point. All salts affect this soil in the same manner, resulting in an increase in apparent specific gravity, sodium carbonate having the greatest effect.

Soil No. 428 shows the same relation between apparent specific gravity and moisture content as soils Nos. 516 and 530. The effect

of salts is very similar and also tends to increase this property to a slight extent.

The two physical properties of soils known as cohesion and apparent specific gravity are more or less dependent upon and governed by the same factors, and it is shown in the table that the effect of varying moisture contents and addition of salts is similar. Both reach a minimum at the point known as that of optimum moisture content, which is conceded to be the stage most favorable to plant growth. Hence these properties are of special significance in soil investigations.

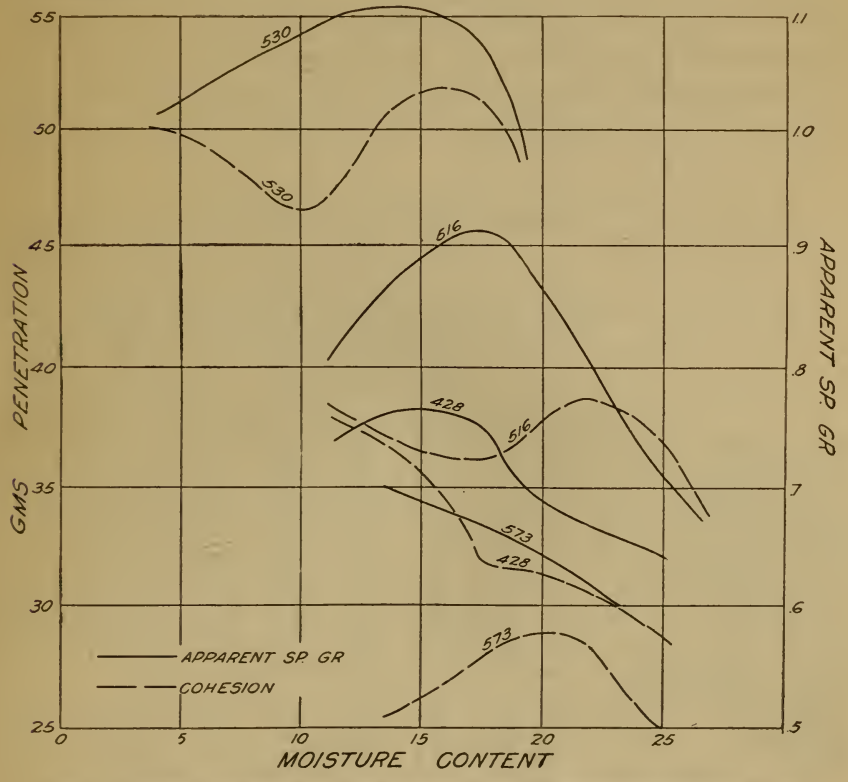

FIG. 3.—Relation between cohesion, apparent specific gravity, and moisture content of soils.

In classifying the Hawaiian types of soil according to these properties, the clay soil possesses the highest cohesive properties, the manganese silt next, the sandy soil third, while the lowest and hence the most easily cultivated is the silty soil, No. 573. The same relation applies also to the apparent specific gravity and is true not only at the optimum moisture content but also on the air-dry soils. The curve shown in figure 3 well illustrates the relationship existing between these two properties of Hawaiian soils. At the lower moisture contents the curves diverge considerably while above a given point they again follow similar lines.

VAPOR PRESSURE.

Comparatively little work has been done on the effect of soluble salts on vapor pressure of soils, i. e., the rate of evaporation. Theoretically salts should increase the surface tension of solvents and thereby lower their vapor pressure and hence increase the water-retaining capacity of the soil. The study made of this property indicates that this theory apparently applies to Hawaiian soils.

As a means of measuring this property of soils ordinary weighing bottles were used. Twenty gram lots of soil with which the various salts had been mixed were placed in these bottles, 12 cubic centimeters, or 60 per cent, of water was added to each and then allowed to stand one week in the open air. Weighings were made at this stage, following which all the samples were placed in the same desiccator with calcium chlorid and weighings were again made after one week. The results are given in Table XII.

TABLE XII.—*Effect of salts on vapor pressure.*

Salts and fertilizers.	Amount added.	Soil No. 530.		Soil No. 573.		Soil No. 428.		Soil No. 516.	
		Water retained.		Water retained.		Water retained.		Water retained.	
		In air.	In desiccator.	In air.	In desiccator.	In air.	In desiccator.	In air.	In desiccator.
	Gm.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Sodium carbonate	0.10	65.3	46.0	39.4	20.9	39.2	31.9	43.7	29.5
Sodium nitrate	.09	71.2	55.5	50.0	33.2	44.1	38.8	46.8	31.4
Magnesium oxid	.04	64.2	43.6	45.7	26.0	44.4	38.2	42.9	24.4
Calcium carbonate	.10	66.2	42.7	41.0	21.6	44.3	35.3	44.9	26.9
Calcium phosphate	.23	52.8	21.0	42.7	15.2	43.0	30.7	45.7	.....
Calcium oxid	.06	58.6	29.7	44.8	24.4	39.8	31.5	44.8	28.3
Potassium phosphate	.21	51.4	26.9	41.3	19.3	42.4	25.4	35.9	15.2
Potassium sulphate	.17	62.7	42.9	48.1	33.6	39.5	31.2	37.8	17.5
Ammonium sulphate	.13	73.9	61.3	41.7	26.4	43.0	31.7	35.6	17.4
Potassium chlorid	.08	50.2	28.2	45.8	21.7	40.2	40.5	44.8	33.8
Superphosphate	.10	63.3	43.3	44.7	27.4	42.8	25.7	38.4	25.6
Acid phosphate	.10	77.0	60.2	45.8	28.5	41.3	15.3	37.3	22.7
Cottonseed meal	.10	32.5	8.0	41.5	9.7	43.3	23.1	43.6	27.4
Blood	.10	42.6	16.2	36.1	7.2	48.7	28.6	43.8	29.9
Acid phosphate and blood	.10	44.0	9.5	31.2	4.3	41.4	24.8	40.7	22.5
Potassium sulphate and acid phosphate	.10	58.2	25.6	40.3	16.2	49.2	30.3	44.1	28.6
2 (NH_4)-14-2[1]	.10	36.5	10.2	39.3	8.3	41.2	19.3	40.6	20.4
1 (NH_4)-9-1[1]	.10	37.8	10.8	35.7	9.6	38.7	17.5	37.2	20.9
2 (NO_3)-14-2[1]	.10	59.6	41.3	45.3	25.6	57.2	22.8	42.4	28.6
Check	.....	48.0	24.6	36.3	15.3	37.0	17.8	35.4	22.1

[1] Fertilizer mixtures containing nitrogen, phosphoric acid, and potash in the order and proportions (percentages) indicated; nitrogen from ammonium sulphate in the first two, from sodium nitrate in the third.

These figures indicate that the effect of salts upon vapor pressure in soils is one of considerable importance. Salts act upon Hawaiian soils more or less according to theory. The major part of them increase the water-holding power in all four soils. Organic substances increased evaporation in soils Nos. 530 and 573, but had the opposite effect upon Nos. 428 and 516. These results also show that the form of nitrogen used in mixed fertilizers bears a definite relation to the vapor pressure. Those in which sodium nitrate was used show a

much greater capacity for holding moisture. In fact, sodium nitrate itself has the most striking effect on all types of soils. There is no apparent classification of the results according to the changes in surface tension which should theoretically result through the addition of the salts.

HYGROSCOPIC MOISTURE.

When a soil has been dried in the air and then is exposed to a moist atmosphere it will reabsorb moisture. The amount which it is able to take up depends upon several factors, such as mechanical composition, presence or absence of organic matter and its state of decay, temperature of the air, and presence of colloidal clay and ferric and aluminum hydrates. This form of moisture, while it is not in itself able to support normal plant growth, may materially assist in sustaining vegetation during drought. Some investigators claim it to be of absolutely no service to plants.

Hawaiian soils, owing to their high humus and ferric hydrate content, possess a very high hygroscopic coefficient. Of the series used in this study the sandy soil was lowest, as would be expected, but even in this case the hygroscopic moisture is high in comparison with normal sandy soils, due to its high organic content.

Table XIII shows the comparative moisture-absorbing power of the types studied. From these data we are led to conclude that, due to the abnormal physical properties of Hawaiian soils, the size of particles is not the primary factor in determining its hygroscopic properties, although surface exposed is an important factor.

The data presented in this table were obtained by exposing a very thin layer of soil in a saturated atmosphere for 144 hours, after which the total moisture was determined. Soil No. 428 having the least exposed surface, the highest percentage of organic matter, and the highest moisture content in the air-dry soil, has the least hygroscopic power. The clay soil, No. 530, has the most exposed surface, the largest percentage of ferric hydrate, the lowest moisture content in air-dry form, the least organic matter content, and next to the lowest absorbing power. But soils Nos. 516 and 573, a manganese silt of high iron content and an organic silt, respectively, soils very dissimilar in chemical composition and physical properties, have the highest absorbing power, with the balance in favor of the manganese soil.

TABLE XIII.—*Percentage of hygroscopic moisture absorbed in 144 hours.*

Soil No.	Hygroscopic moisture.
	Per cent.
530	19.32
573	21.59
428	15.56
516	24.04

Table XIV shows the effect of salts upon the hygroscopic power of soils. That this property should be affected by the addition of fertilizers was to be expected, since most salts possess this property themselves to a greater or less extent, and it is only natural that they should impart it to soils. These experiments were conducted by exposing a thin layer of soil to a saturated atmosphere in two large containers. Conditions were made as nearly similar as possible, but blank samples of soil were exposed in each as checks. Salts were well mixed with a bulk of soil at the rate of 0.5 per cent of salt, and weighings made from this bulk. Samples were exposed for 48 hours and total moisture determined in the air bath at 105° C.

TABLE XIV.—*Effect of salts and fertilizers on hygroscopic moisture.*

Salts and fertilizers.	Soil No. 530.	Soil No. 573.	Soil No. 428.	Soil No. 516.	Soil No. 542.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Original moisture content of soils	3.17	10.84	9.87	5.54	4.12
Potassium sulphate	17.21	19.35	14.80	21.40	18.45
Calcium oxid	16.78	19.80	14.05	21.30	16.10
Acid phosphate	16.76	17.88	13.90	19.90	16.42
Ammonium sulphate	17.08	18.70	15.53	21.15	20.30
Sodium nitrate	17.28	24.80	17.45	22.20	20.10
Sodium carbonate	17.64	24.20	15.80	21.30	17.95
Check	16.35	18.90	14.55	20.70	16.11
Calcium sulphate	16.26	20.81	13.70	21.20	17.30
2 (NH_4)–14–2[1]	16.90	20.20	14.70	21.50	16.80
2 (NO_3)–14–2[1]	16.56	22.00	15.08	20.50	17.06
Superphosphate	17.07	20.30	13.80	21.40	16.70
Potassium sulphate and acid phosphate	16.50	18.50	14.35	21.80	16.60
Sodium chlorid	18.95	32.00	22.02	30.00	22.50
Check	16.35	18.58	14.58	21.10	16.18

[1] Fertilizer mixtures containing nitrogen, phosphoric acid, and potash in the order and proportions (percentages) named; nitrogen from ammonium sulphate in the first, from sodium nitrate in the second.

The effect of adding salts upon the ferruginous clay is to increase the hygroscopic power in every instance, except where calcium sulphate is added, in which case there is very little variation. As a matter of fact the general tendency of all the salts on the different types is to increase this property of soils, and in cases where there is a decrease it is almost negligible. Sodium chlorid, being itself a hygroscopic salt, imparts the highest absorbing power to the soil, while the lowest is effected by addition of acid phosphate.

SUMMARY.

The foregoing pages contain data obtained from an extensive study of the physical properties of Hawaiian soils and the effect of fertilizers upon these properties. It is evident that agents which influence the mechanical condition are many and complex. It has also been clearly demonstrated that the addition of salts or fertilizing materials affects the structure of the soil.

It is impossible to predict in all cases the degree to which any one or all physical properties will be influenced by the addition of a fer-

tilizer, since this depends primarily upon the mechanical composition of the soil, the nature of the organic matter, and probably upon certain factors which are at present unknown. However, within certain limits, the effect of adding a larger application of a salt only magnifies that of a smaller application. This suggests that the measurement of the physical effect may be just as accurately, and possibly more accurately, determined than the chemical effect. The measurement of a normal application of fertilizer through a chemical analysis of the soil is practically impossible.

Capillarity is diminished in clay soils by the addition of salts but increased in sandy soils. Also this property is more active in silts than in sandy or clay soils, being slowest in the latter.

The percolation of water is most rapid in sandy soils and slowest in types the particles of which are most likely to swell. Fertilizers considerably increase the resistance to percolation. The theory that soils of greater capillary activity offer the least resistance to percolation of water does not apply to Hawaiian soils.

Salts increase or diminish the size of the soil aggregates. This is of no small importance in the use of fertilizers.

The cohesion of the soil particles in most instances is increased by the addition of salts. This is also true of the apparent specific gravity. However, there are too many exceptions to make any definite statement.

The hygroscopic moisture is increased by the addition of salts, with but very few exceptions.

The vapor pressure is lowered in most instances, but can not be explained from a consideration of the surface tension of the added salts.

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